The Starrett Transit Book

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The Use of the Starrett Transit

CONTENTS

THE L. S. STARRETT COMPANY
World's Greatest Toolmakers
ATHOL, MASSACHUSETTS, U. S. A.

The Starrett Transit and Level

These instruments have been made to meet the needs of farmers, contractors, and builders who do not care to invest in an expensive engineer's instrument, or who have not had sufficient training in mathematics to make the refined measurements of which such an instrument is capable. In price, the Starrett instruments are within the reach of all who have to do measuring and leveling, and because of their simplicity they can be used by anyone who is willing to exercise ordinary care. In general, it may be said that the Starrett transit or level can be used for the same purposes as the engineer's transit or level, that is, for determining the amount of fall in locating drains, finding the height of springs, laying out the founda-

tions for buildings, and in the building of dams and raceways for simple water-power developments.

If the magnetic bearings of the lines are not required, these simple instruments will be found superior to the ordinary needle compass in taking angles, especially in places where, on account of local attraction, the compass needle is unreliable.

The farmer finds continual use for this instrument in laying out his fields, when planning crop rotations, planting orchards, and similar work. In conjunction with neighbors he uses the transit for laying out roads and side ditches, thereby insuring proper grade for drainage.

The transit is especially valuable to the farmer in connection with the laying out of tile drainage or irrigation systems where the grade must be known in order to lay out the system properly.

The builder or contractor uses the transit in laying out foundations, setting batter boards, leveling for grading, or setting forms for pouring monolithic concrete floors.

Millwrights and machinists may use the Starrett transit or level to advantage in leveling and aligning shafting in a mill or factory.

The Starrett transit, No. 99 (see page 44), combines in one instrument the facilities for measuring both horizontal and vertical angles, and for leveling work, thus enabling the operator to lay out anything that does not require excessive refinement. The level or leveling instrument, No. 101 (page 45), is for measuring angles in a horizontal plane only, or

for leveling work. In this booklet the use of the transit will be described, but it should be borne in mind that the level will do all that the transit will, except measure vertical angles.

The lenses in our telescopes give what is called "10 power vision," that is, objects appear to be magnified 10 times as large (diameter) when seen through the telescope as they are when seen without the telescope. Fairly accurate work can be done with these telescopes up to distances of 500 feet or more. When using the plain sight tube points can, of course, be set or measurements taken at any distance at which the operator can see, but the accuracy of the results is necessarily less than when using the telescope.

Care of Instrument

The Starrett transit is sturdily built and will stand hard usage. But it should not for this reason be abused or treated carelessly. If you expect good results from your transit, give it reasonable care.

Do not let it fall or receive a heavy jar. Keep the thumb screws on the tripod legs tightened up firmly when in use so that the tripod cannot give way and injure the telescope.

Do not allow the lenses to become dusty or greasy. If the lenses are protected by the caps over the object glass and the eyepiece when the telescope is not in actual use, the telescope will last much longer. Dust may be removed by use of a camel's-hair brush, or a soft, clean handkerchief. Grease may be removed by

using a drop of alcohol on a cloth and then wiping the lens dry with a clean, dry part of the cloth. Avoid using too much alcohol, or it may dissolve the cement between the lenses and render them unfit for use until they have been sent to the factory for repairs. Much rubbing will scratch the lenses and should be avoided. Do not unscrew the object glass from the telescope, or its adjustment may be changed and cause errors in your work. If the lenses must be cleaned on the inside, it should be done by someone who understands readjusting the entire instrument.

Test the adjustments occasionally, whenever you suspect that they may be out, or before doing an important job. The adjustments are not difficult to make and are fully explained in this booklet.

When the instrument is being carried, either in or out of its box, or whenever it is not being used for actual leveling work, loosen the binding screw on the quadrant (vertical angle plate) and also the nut above the level vial which holds the telescope; this leaves the telescope free to move so that if it strikes against any object or receives a jar there is

less likelihood of the instrument's being thrown out of adjustment.

To use the instrument as a level, insert the pin (P) (Fig. 2, page 10), and clamp the set screw (D) on the vertical arc.

To use as a transit, remove the pin. The telescope may be clamped in any position, as when taking vertical angles.

How to Set Up and Level the Instrument

Give the tripod legs sufficient spread so that the instrument will be steady, and push the legs into the ground firmly so that neither the wind nor an accidental touch will disturb the adjustment. If the transit is being set over a point, such as a tack in a stake, move the whole instrument so that the point of the plumb bob is over this point. Level the plate as nearly as possible (by eye) by adjusting the length of the lower parts of the extension legs of the tripod. Set the tripod clamp screws *tightly* to avoid accidents and inaccurate results. Finish the leveling by means of the four leveling screws as follows: Loosen the screw beneath the tripod, turn the telescope so that it is over one pair of opposite leveling screws, grasp both leveling screws between the thumb and forefinger and turn them so as to loosen one and tighten the other at the same time. This is done by turning so that the thumbs move either toward each other or away from each other, according to which way the bubble is to be moved. Bring the bubble to the center of

the tube. Next turn the telescope at right angles (90°) and center it again by means of the other pair of leveling screws. Repeat in both positions for a check. If the level is in adjustment the bubble will now remain in the center no matter in what direction it is turned. The leveling screws should be neither too tight nor too loose, but bearing evenly and firmly. If too loose, there will be errors in the work; if too tight, the instrument will be strained. Leveling the instrument may throw the point of the plumb bob off the tack. In this case, correct the position of the instrument and level it again.

Do not let your overcoat drag against the tripod or allow your hand to rest on the instrument while you are making measurements. It will surely cause errors if you do.

How to Test and Adjust the Instrument

Before doing any important piece of work, such as laying out a building or setting forms for concrete, it is advisable to test the adjustments of the instrument. A few minutes spent in touching up the adjust-

ments may save a considerable sum of money. If the instrument has had a fall or a jar it should certainly be tested before it is used again.

To test the spirit level, first level the plate as already described for setting up the transit (page 7). Then test the adjustment of the level by centering the bubble and then reversing the telescope (end for end, 180°). If the bubble still remains in the center of its tube, the level is in adjustment. If the bubble moves out of center, bring it *half-way back* by means of the slotted adjusting screws on the level case. Level the plate again and repeat this test. When the bubble remains always central as the telescope is turned slowly around the plate, the level is in adjustment and the plate is horizontal.

To test the telescope to see if the line of sight is level when the bubble is central, proceed as follows: On a piece of ground which is fairly level drive a stake into the ground and drive a nail into the stake (A, Fig. 1). From A, measure off 100 feet, or some

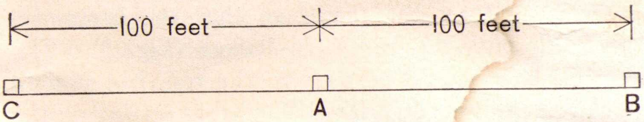


Fig. 1

other convenient distance, and set a stake B. In about the same line set a third stake C, the distance AC being equal to AB. Remember that the tops of stakes B and C are finally to be set exactly to the same level, so the ground at these points must be nearly the same level. Now set the transit over

stake A, so that the plumb bob is over the nail and the plate is perfectly level. Unclamp the screw (D) (Fig. 2) and place the pin (P) in the hole (H) and press it in firmly. Hold the pole, or rod, on

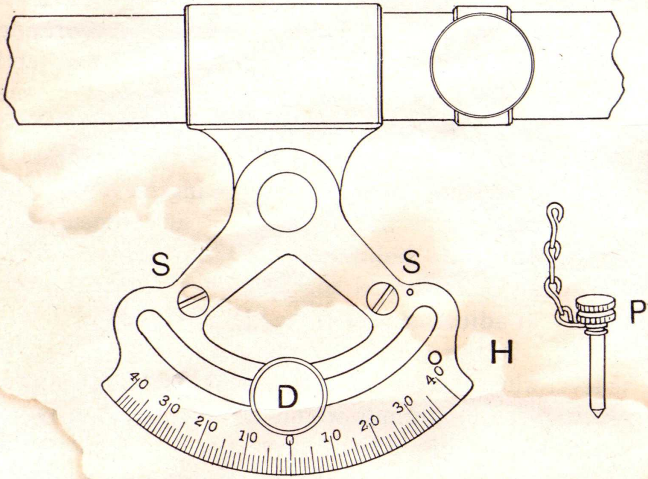


Fig. 2

stake B and set the target so that the horizontal cross-hair cuts the target in halves (Fig. 3). The vertical hair should be near to the rod, but it does not need to bisect it. Read the target setting on the scale and make a note of it. Then carry the rod to stake C. Do not change the target setting, but change the stake, up or down, until the cross-hair bisects the target when the rod is held on this stake, and the bubble is in the center. If the stake has to be raised, pull it up too far and then drive it back, a little at a time, until it is at the right height. This

must be done carefully as the accuracy of the result depends upon these two stakes being set exactly at the same level. The two stakes will be at the same level, even if the instrument is in error, because the distances AB and AC are equal.

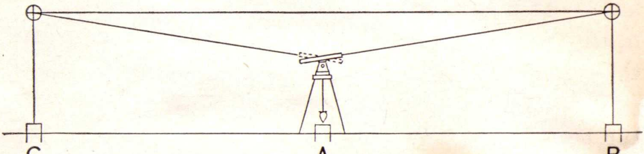


Fig. 3

Now set up the transit about 3 or 4 inches to one side of the stake B and level the plate carefully. Set the rod on top of the stake and adjust the target until the center is at the same height as the center of the telescope tube (Fig. 4). This can be judged quite accurately. Leave target at this same setting and carry the rod to stake C. Center the bubble if necessary and see if the horizontal cross-hair bisects the target. If it does not, the telescope must be adjusted as follows: Check the setting of the telescope by loosening the knurled clamp (D) (Fig. 2), placing pin (P) in hole (H) and pressing it in *firmly*. See that zero line of the arc coincides with line on index. Then tighten the clamp (D). Now loosen the two screws (S) on the graduated arc,


Fig. 4

and move the telescope up or down until the horizontal cross-hair bisects the target. Tighten the screws (S). The instrument should now be in adjustment. To be certain that all is right, check the leveling and again test the setting of the cross-hair. This is a quick way of bringing the telescope nearly into adjustment. For a closer adjustment, the method of the next paragraph should be used.

Another way of testing the cross-hair is to set up the transit about 20 feet away from stake C; center the bubble, and with rod on C set target to the cross-

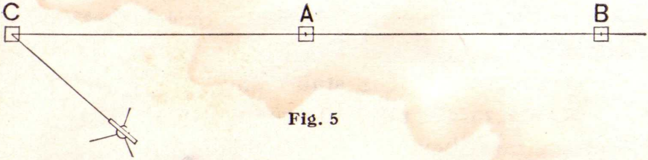


Fig. 5

hair (Fig. 5). Then with rod at B test the cross-hair as before. If the cross-hair bisects the target, the adjustment is good. If it does not, then adjust the telescope (by screws S) to the target. Test again on stake C, moving the target if necessary. Then test on stake B, moving the telescope if necessary. This may be repeated until the same reading is obtained at both stakes without adjustment. On the near stake always adjust the target; on the distant stake always adjust the telescope.

NOTE. The Starrett Level is tested in the same way as the transit. When making the adjustment of the telescope (rod on distant point B) use the two headless set screws in the back frame nearest the object end of the telescope or sight tube. Loosen

one screw and tighten the other. To raise the front end of the telescope unscrew the top screw and screw the bottom screw in. To lower the front end move the screws the opposite way. Be sure there is no looseness when the adjustment is completed. Both screws should be set firmly.

To Test the Vertical Cross-Hair

When the transit leaves the factory, the vertical cross-hair has been adjusted and it cannot be changed. If it has become loosened through accident, the transit should be sent to the factory for repairs. To test it, first level the plate carefully and then sight on the corner of a building or on a plumb string suspended some 20 feet from the transit. The cross-hair should cover the plumb string.

To Test the Vertical Motion of the Telescope

Level the plate, sight the intersection of the two cross-hairs on the top of some line known to be vertical, as the corner of a brick or stone building. If the building is tall, the transit may be set some distance away; if it is a low building, the transit should be nearer; the idea is to be able to move the telescope through an angle of 30° to 45° when moving from the top to the bottom. While the cross-hair is sighting the top of the line, tighten the clamp beneath the tripod so the telescope cannot move sidewise. Lower the telescope to sight a point near the bottom of the vertical line and see if the intersection of the two cross-hairs is still on this line.

If it is not, there is an error in the adjustment; the transit cannot be adjusted in the field, but must be sent to the factory for repairs. If the error is but slight, however, and the transit is not to be used for lining in vertical objects, such as columns in a building, this error will not be serious. In leveling, or in measuring horizontal angles between points about on the same level, or in measuring vertical angles, this error will have little or no effect.

To Find the Difference of Level of Two Places

If the instrument can be set up in such a position C (Fig. 6) that both of the places A and B are visible,

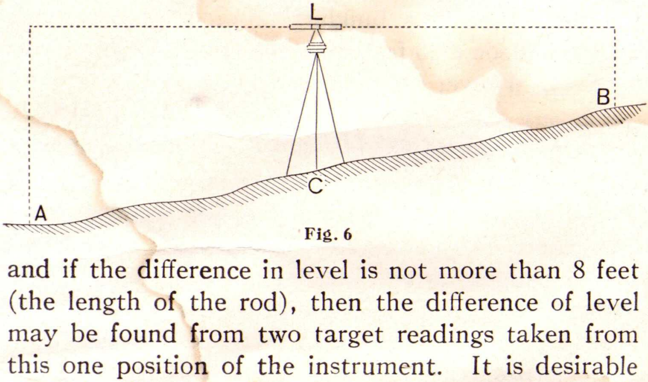


Fig. 6

and if the difference in level is not more than 8 feet (the length of the rod), then the difference of level may be found from two target readings taken from this one position of the instrument. It is desirable that the distances from C to A and from C to B should be about equal. The plate must be leveled and the telescope must be locked in the level position by means of the pin. Hold the rod at A and set the target to the horizontal hair in the telescope or sight tube and record the reading in the notebook.

Suppose this reading to be $7' \, 4\frac{1}{4}''$. Then carry the rod to B and again set the target to the cross-hair. Suppose this reading to be $3' \, 7\frac{1}{4}''$. Then the difference, $3' \, 9''$, is the amount that B is higher than A. The place at the higher level always has the smaller target reading.

When there is a large difference in level, or when the distance is great, or when there are obstacles in the line, it becomes necessary to set the level in more than one position. In this case select a number of intermediate points along the line, such as tops of stones, or stakes driven firmly into the ground; then by the same process as that already described find the difference of level between the first and second points, then between the second and third points, and so on to the end. In Fig. 7, it is desired

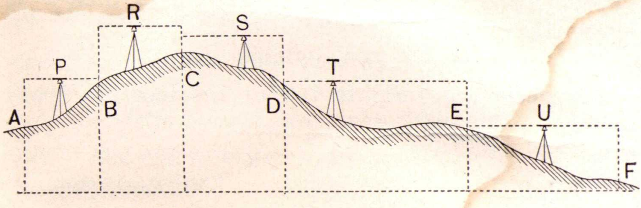


Fig.7

to find the difference in level between A and F. The instrument is first placed in some such position as P, and leveled, and target readings are taken at A and at B. The result will be more accurate if the instrument is so placed that the distance AP is nearly equal to the distance PB. The target reading with rod at A is put down in the notebook as a "back

sight" (4′ 0″), see table below; that at B is a "foresight" (0′ 6″). The instrument is then taken to R, about equally distant from B and C, if the ground permits. From R we take a back sight on B (7′ 6″) and a foresight on C (2′ 0″). This process is continued until finally a foresight is taken on F (6′ 0″). Look at the level each time a sight is taken to be sure it has not moved from the center. The notes may be conveniently kept in the form shown in the table. The sum of all the backsights is the amount which has been measured upward, from ground to instrument; the total of the foresights is the amount that has been measured downward, from instrument to ground. The difference between these two sums (7′ 6″) is the difference in level between points A and F. If the sum of the foresights is greater than the sum of the backsights then F is lower than A.

Do not try to take very long sights unless absolutely necessary. Sights 100 to 200 feet away will give better results than long ones.

NOTEBOOK

Point	*Backsights*	*Foresights*
A	4′ 0″	....
B	7′ 6″	0′ 6″
C	1′ 6″	2′ 0″
D	0′ 6″	7′ 0″
E	1′ 0″	6′ 6″
F	....	6′ 0″
Sums	14′ 6″	22′ 0″
		14′ 6″
Difference in level of A and F		7′ 6″

Setting Points at Same Level

If several points are to be set at the same level, as when leveling up forms for a concrete foundation, the instrument should be set up and leveled and the telescope fixed in position by means of the pin. The rod is held on some point which is at the required level and the target set so that it is bisected by the horizontal cross-hair. Make a note of this target reading. Do not change the target, but keep it set and clamped at this same reading. To set any point at the required elevation, hold the rod at that point, and raise or lower the *entire rod* until the target is bisected by the cross-hair. The foot of the rod is now at the required height and a mark may be made, or a form fixed in position, so as to touch the bottom of the rod.

To Measure a Horizontal Angle

Set the transit over the point (B, Fig. 8) which is to be the vertex of the angle and level the plate. Sight the telescope or the sight tube along the first side of the angle (at point A) and tighten the clamp beneath the tripod to hold the telescope in this position. Loosen the clamping lever which holds the horizontal arc and turn the arc until the index finger can be pushed into the zero mark by means of the push pin. Tighten the clamping lever. Then loosen the clamp below and turn the telescope until it sights along the second side of the angle (to point C); then clamp below. The angle is read on the arc by means of the index finger. If the finger will go into one of

the graduated lines the angle is an exact degree; if not, then the fraction of a degree must be estimated as nearly as possible.

To Lay Off a Horizontal Angle

In order to lay off an angle (say an angle of 90° at the corner of a proposed building) proceed as described for measuring an angle, except that when about to sight along the second side of the angle see that the index finger is pushed into the required degree in the arc (90°), and then clamp the lower clamp. The point indicating the second side of the angle (as point C, Fig. 8) must be moved to the right or left so as to bring it in line with the vertical cross-hair. It is then in the correct position.

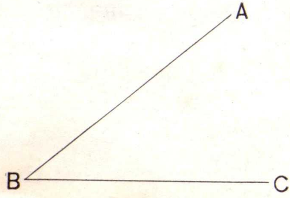


Fig. 8

To Measure a Vertical Angle

Level the plate, loosen the binding screw on the vertical arc and remove the pin. Raise or lower the telescope until the horizontal cross-hair covers the point the vertical angle of which is required. Lock the telescope with the binding screw which holds the arc in this position. The required vertical angle is read at the index line.

To Run Out a Straight Line

This would be required if points were being lined up for a fence, or a ditch, or rows of trees. Set the transit over one end of the line (A) (or some other

fixed point on the line) and level it. Sight the vertical cross-hair on the other end of the line (B), and tighten clamp screw beneath the tripod to hold the telescope in line. Any point (C, D, E, etc.) that is brought to the line of the vertical hair is on

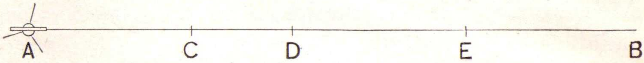


Fig. 8a

this required line. Do not trust the instrument to remain pointed for a long time; check the sight on the end point from time to time.

To prolong the line farther, set the transit at a point E, sight point B and clamp below. Points beyond B may now be set in line with the cross-hair.

To Lay Out a Building and Set the Batter Boards

Let us suppose that a rectangular building is to be laid out (Fig. 9). First decide upon the position

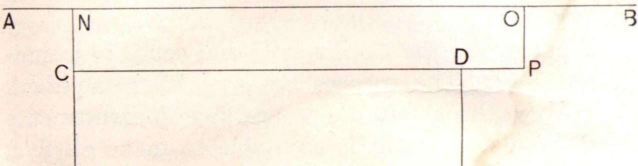


Fig. 9

of one corner (C) and the general direction of a side (CD). If the building is to be parallel to a street

line (AB) measure back from the street line in two places (NC and OP) so as to establish the parallel. Set up the transit so that the point of the plumb bob is over point C, and level the instrument. Sight the telescope at P and clamp (below) in this position. Measure CD equal to the length of the front of the building (say 100 feet). Set a stake, or other mark, at D in line with the cross-hair.

To lay off CF at right angles to CD, leave the telescope or sight tube still sighting at D, turn the graduated arc until the index finger can be pressed into the zero mark by means of the push pin. Clamp the graduated arc in that position by the clamping lever. Then loosen the lower clamp screw and turn the telescope until the index finger will fit into the 90° mark. Clamp the telescope in this position. Point F is to be set along this line and distant from C an amount equal to the short side of the building (say 50 feet).

Next set up the transit at D and set E in a similar manner. The corners are now all established. To verify the work, there are five measurements we may make, and it is advisable to make all five, as errors are easily made, but expensive to remedy if discovered too late. Side FE should measure the same as CD. With the transit at E and then at F, test the angles to see if they are 90°. Finally measure the two diagonals CE and FD. If these are exactly equal, you may feel sure that all is well.

If the building, instead of being one rectangle, has several projecting or re-entrant parts, as in Fig.

10, the main rectangle may be laid out first, and the smaller rectangles laid out afterward in just the same way. If you start at one corner and go around the building by many turns and by short

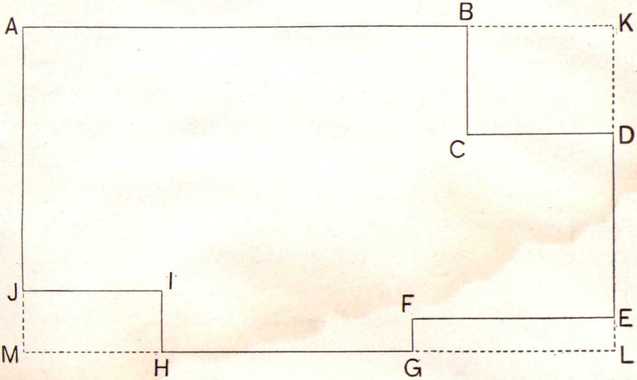


Fig. 10

measurements, the errors will accumulate. But, if you establish a large rectangle first, say AKLM, and then lay off from this the small rectangles, BKDC, ELGF, and HMJI, the errors cannot accumulate to the same extent.

In setting the batter boards, it is usually better to get them at the right level first, and then afterwards drive the nails for holding the strings. Set the transit near the middle of the building and level it with the pin in place to hold the telescope level. Decide upon the height for the masonry, and make a mark at this height. Hold the rod so that its bottom edge is on this reference mark. While it is in this

position, set the target to the horizontal cross-hair. The target is to be clamped tightly and kept clamped in this same position until all boards are set. Set the rod on top of the board at N (Fig. 11) where a

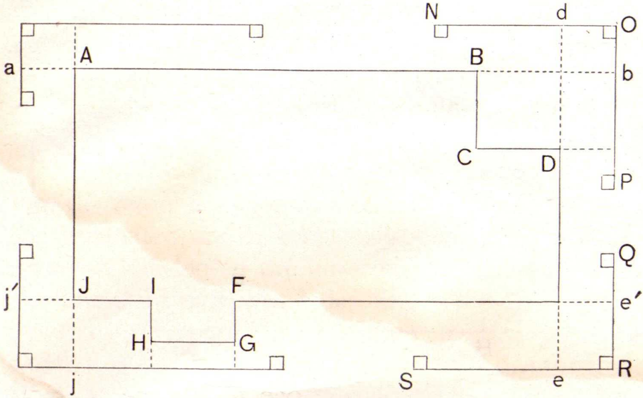


Fig. 11

stake has been driven. Raise or lower the board until the target is on the cross-hair, then nail the board to this post with one nail. Then hold the board at a post at O (with the rod resting on the board) and again bring the target on level with the cross-hair and nail the board. The next board from O to P is set in the same way. This is continued around the building. Sight around the boards and across the corners to be sure no blunders have been made. When all boards are set and appear to be correct, extra nails may be driven.

To establish the lines, set the transit over stake A and level it. Sight toward B and clamp below. Use a plumb bob at B to sight at if necessary. Then set a nail at b on the top of the board and in the same line as B. While at point A, turn toward J and set a nail j in line with J. Next move the transit to B and level it. Sight at A and set nail (a) in line. A string stretched from a to b marks the front line AB. In a similar way set nails at all points needed such as d and e, e′ and j′, etc. The boards must be made long enough to cover such lines as FG, HI, etc., otherwise it will be necessary to drive extra stakes and set extra boards. The level of the top edge of the boards may be tested while the transit is at point A, or B, by noting if the target is always on the cross-hair no matter which board the rod is held on. Of course, this target setting will not be the same as the previous one unless the telescope happens to be set at the same height.

Degree of Slope

Sometimes it is desired to know the degree of slope which corresponds to any amount of drop per 100 feet.

To find the vertical angle corresponding to any slope, reduce the slope to a decimal fraction, that is the rise or fall per foot, by dividing the rise or fall by the distance; find this number in the table of *tangents* (page 43); the angle corresponding is the required vertical angle.

For example, if there are two fence posts 800 feet apart and one is 16 feet below the other, we

then have a drop of two feet in every 100 for a straight line between the two. Two feet in 100 is .02. If we look in the table of tangents (page 43), we find that the corresponding angle is just about 1 and $\frac{1}{6}$ degrees. The index mark should read 1 and $\frac{1}{6}$ degrees on the vertical arc when the telescope is inclined at this slope of 2 in 100. The fraction of a degree must, of course, be estimated as nearly as possible. If, while the telescope has this inclination, the tops of all intermediate posts are cut off in line with the horizontal cross-hair, they will be on a slope of 2 per cent. A simpler way of doing this, however, is given on page 25.

The following table may be found useful in determining the relation between the angle of slope and the rise or fall in inches for various distances in feet. For instance, we find from the table that a drop of 15.71 inches in a distance of 75 feet correspond to a slope (or vertical angle) of just 1°.

ANGLE		LENGTH IN FEET							
		25	50	75	100	125	150	175	200
$\frac{1}{4}$°	Drop in inches	1.30	2.61	3.92	5.23	6.54	7.84	9.15	10.46
$\frac{1}{2}$°		2.61	5.23	7.85	10.47	13.09	15.71	18.33	20.95
$\frac{3}{4}$°		3.92	7.85	11.78	15.71	19.63	23.56	27.49	31.41
1°		5.23	10.47	15.71	20.95	26.19	31.43	36.66	41.90
1$\frac{1}{4}$°		6.54	13.09	19.64	26.18	32.73	39.27	45.82	52.37
1$\frac{1}{2}$°		7.85	15.71	23.57	31.43	39.28	47.14	54.99	62.85
1$\frac{3}{4}$°		9.16	18.33	27.49	36.66	45.82	54.99	64.15	73.32
2°		10.47	20.95	31.43	41.90	52.38	62.85	73.33	83.80

"Shooting In" a Grade Line

A very simple way of obtaining a uniform drop in any given distance is as follows:

Drive a stake at the desired height at the end of the proposed line and set up the instrument over this stake. Measure with the pole, or a tape, the height of the telescope above the stake; suppose this is 3 feet 9 inches. Measure off the required distance between stakes, say 100 feet, and set another stake. Now raise the target the amount the drop is to be, say 6 inches. This would make the target read 4 feet 3 inches. Drive the stake until the target is on the cross-hair. The line between the stakes now drops 6 inches in 100 feet. To set the telescope to this same inclination, set the target back to its first reading (3 feet 9 inches) and incline the telescope downward (by means of the vertical motion, or by the leveling screws) until the cross-hair is again on the target. Now if the pole is carried to a point 200 feet from the instrument and a stake driven until the target is on the cross-hair this third stake will be on the same grade. As many others as desired may be set along the same line. The target must be kept clamped at the same reading (3 feet 9 inches).

Drainage

If land is to be drained by tiles, the different sections should have uniform grades. It is not usually best to try to have all parts of the line on the same grade, as this would result in some of the

pipe being buried too deeply, and hence useless, and part of it out of ground, or too near the surface. Take levels at places where the slope of the ground makes abrupt changes (as at A, B, C, D, E, Fig. 12), and from these decide where to break the grade of the pipe so as to give it a nearly uniform amount of cover.

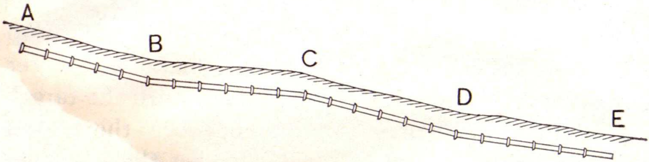


Fig. 12

Survey of Land

The survey of land for a deed, or the subdivision of property involving a transfer of title, is an important matter and should be done with accuracy and care. Usually it is better to have such work done by a surveyor who is perfectly familiar with the details and who is equipped to do the work accurately. It may save costly mistakes.

But occasionally the area of a plot is needed or an area is to be subdivided for some purpose not involving legal boundaries and such problems may be worked out successfully by anyone who does the work carefully both on the field measurements and the calculations.

To Find an Area

Suppose we wish to find the total area of the plot shown in Fig. 13. The bearings and the distances are as follows:

Side	*Length*	*Compass Bearing*
AB	412′	N 76° E
BC	219′ 4″	N 33° 10′ W
CD	276′	S 62° W
DA	158′	S 13° W

From the bearings we find that the angles at the corners are: A=63°, B=70° 50′, C=95° 10′, D=131°.

These angles might be measured with the transit and no compass bearings used at all. The enclosed area can be found from the lengths and the angles.

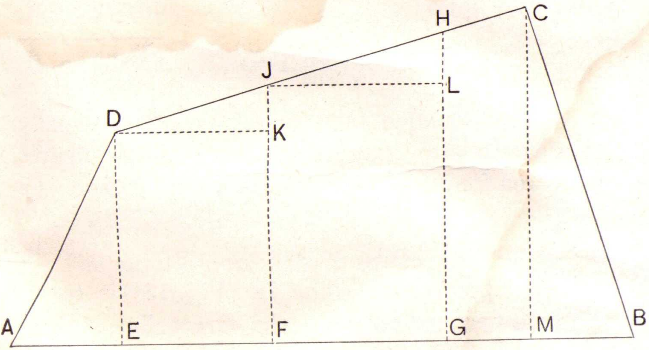


Fig. 13

Drop perpendiculars DE and CM on to the side AB. Then we see that the area is subdivided into two right triangles, ADE and BCM, and a trapezoid

DEMC. By trigonometry calculate the distances AE, DE, BM and CM. (See page 37 for explanation.)

$$AE = AD \cos A = 158 \times .45399 = 71.73$$
$$DE = AD \sin A = 158 \times .89101 = 140.78$$
$$BM = BC \cos B = 219'\,4'' \times .32832 = 72.01$$
$$CM = BC \sin B = 219'\,4'' \times .94457 = 207.18$$

From the dimensions we then find the following areas:

Area of triangle ADE=
$\frac{1}{2}DE \times AE = \frac{1}{2} \times 140.78 \times 71.73 =$ 5,049 sq. ft.

Area of triangle BMC=
$\frac{1}{2}BM \times MC = \frac{1}{2} \times 72.01 \times 207.18 =$ 7,459 sq. ft.

Area of trapezoid EDCM=
$\frac{1}{2}EM(DE + MC) = \frac{1}{2} \times 268.26 \times 347.96 =$ 46,672 sq. ft.

Total area of ABCD= 59,180 sq. ft.

Any area bounded by straight lines can usually be divided up into triangles or other simple figures and the area found in a similar manner.

Subdivision of Land

Let us suppose that a line JF (Fig. 13) is to be established perpendicular to the street line AB so that it will cut off an area of one-third of the total, or 19,727 sq. ft. This area, AFJD, will contain the triangle ADE=5,049 sq. ft. and the trapezoid DEFJ=14,678 sq. ft. (the difference between 19,727 and 5,049). The most practical way to find the

dimensions of this trapezoid is to assume a distance EF (=DK) and then calculate the area. If this area proves to be too small, move the line FJ to the right and make a second trial. If the plot is laid down on paper, the position of JF can be judged fairly well. Let us assume that EF=DK=100 ft. Then, JK is $100 \times \tan 14° = 24.93$ ft. (angle JDK $=14°$). The entire angle at D is 131°. Since angle $A=63°$, the angle ADE its complement$=27°$. EDK is a right angle, or 90°. The sum, or 117° taken from 131°, leaves 14° for JDK.

$$\begin{aligned} \text{The area, } DEFJ &= DE \times DK + \tfrac{1}{2} \times JK \times DK \\ &= 140.78 \times 100 + \tfrac{1}{2} \times 24.93 \times 100 \\ &= 15{,}324 \text{ sq. ft.} \end{aligned}$$

This is 646 sq. ft. too much, so we must shorten EF so as to take off a strip having a length equal to JF, or 165.71 ft., and an area of 646 sq. ft. The width of this strip will be nearly $646 \div 165.71 = 3.90$ ft. This makes the new length of EF=96.10 ft. The new length of $JK = 96.10 \times \tan 14° = 23.96$ ft.

The new area of DEFJ=

$$140.78 \times 96.10 + \tfrac{1}{2} \times 23.96 \times 96.10 = 14{,}680 \text{ sq. ft.}$$

The area is now only 2 sq. ft. too large. If we shorten EF by .01 ft., making it 96.09 ft., the area is then correct to the nearest square foot. This makes $DJ = 96.09 \div \cos 14° = 99.03$ ft. If we measure off 99.03 ft. from D toward C and set a point in line with the transit, we fix the position of J. If we measure 96.09 ft. from E toward B and line it in, we fix the position of F.

In a similar manner we may establish HG, which cuts off another third of the entire plot. FG will be 110.5 ft.

To Find an Irregular Area

An area bounded by a curved line, like the bank of a stream, is best found by measuring off equal distances along a straight line and then taking "offsets," or perpendicular measurements from the straight line to the curve. Suppose that area ABCD (Fig. 14) is to be found, and that BC is the curved

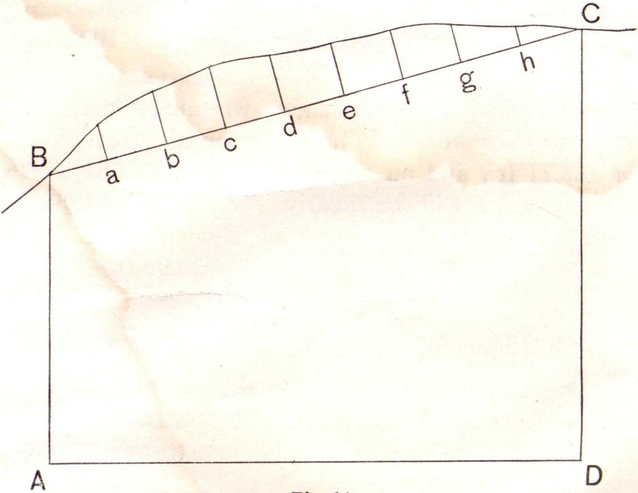


Fig. 14

line. If we measure straight across from B to C and leave stakes, say every 10 feet, we may then easily find the area bounded by the straight lines

AB, BC, CD and DA, and add to it the areas of the series of little trapezoids formed by measurements from BC to the stream. At a, b, c, etc., distances are taken at right angles to BC out to the edge of the stream. Any two of these distances, such as those at b and c, give a trapezoid with a perpendicular distance of 10 feet between offsets. Suppose that a=6.0 ft., b=7.0 ft., c=8.0 ft., d=7.6 ft., e=5.6 ft., f=5.0 ft., g=3.0 ft., and h=2.0 ft.; also suppose that hC=only 8.2 ft. The area of any trapezoid, like that between b and c, $= \frac{1}{2} (7.0+8.0) \times 10=75$ sq. ft. If we consider only the trapezoids which have 10 ft. bases, we may shorten the calculation as follows: add half the end offsets and all the intermediate offsets and multiply the sum by the distance (base) between them.

Then we have

$$\text{Area}=(3.+7.0+8.0+7.6+5.6+5.0+3.0+1.0)\times 10=402 \text{ sq. ft.}$$

The little triangle on the base, hC=8.2 ft., must be taken separately because the length of the base is different; its area is $\frac{1}{2} (2.0\times 8.2)=8.2$ sq. ft., making a total of 410 sq. ft.

To Run Out a Random Line

If a line is to be started from a known point and run through woods to another known point, but which is invisible from the first, it is often necessary to run first a trial line or random line. When the error of the trial line becomes known the positions of points on the true line may be found by calcula-

tion. If a line is to be run from A to B (Fig. 15), we start out with a transit at A and run the line in a direction supposed to be about right, and set a point c and then another point d on the line. The transit is next taken to c and sighted at d and another

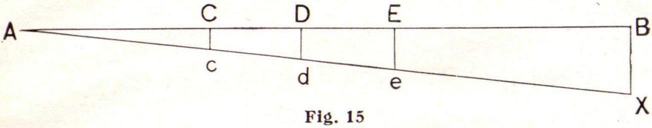


Fig. 15

point e is set farther ahead. This process is continued until point X, opposite B, is reached. As we proceed along this line we measure the distances Ac, cd, de, etc. When at X, we measure the distance XB. The position of any point such as D on the true line, opposite one of the points on the random line, may be found by proportion. Then dD : BX = Ad : AX. That is, if BX is 8.2 ft., Ad=400 ft., and AX=910 ft. Then

$$dD = \frac{400}{910} \times 8.2 = 3.6 \text{ ft.}$$

In a similar manner points C, E, etc., may be established.

Passing Obstacles

Suppose that, while running out a straight line, we find that it is going to pass through a building or other obstacle. We may easily pass to the right or left of it and continue on the original line and also

obtain the distance along the line. In Fig. 16 suppose that we are to run our line from A toward C. When at A we turn off an angle of 120° from any point back of A on the line passed over. To do this, start with the index at 90° on the arc, turn to 0° and

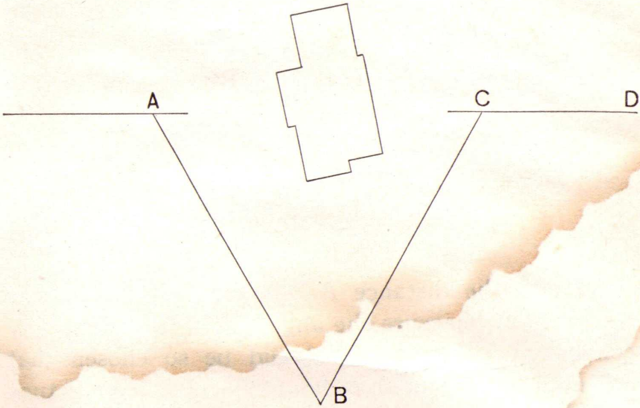


Fig. 16

then beyond it to 30°. Or, we may set a mark no line on the building and turn an angle of 60° to the right. The telescope is now pointing at B. Toward B measure off AB=100 feet, or any other convenient distance. Set the transit at B and turn off 60° from A to the right to C. Measure off BC=AB, and set stake C. Then with the transit at C, turn off an angle of 120° (or 60° from a point on BC prolonged) so as to obtain the direction of line CD. This line (CD) is in the continuation of the original line, and the omitted part AC is exactly equal to AB or BC.

To Measure Across a Water Surface

If a straight line crosses a pond or a stream and a tape cannot be stretched across it, it becomes necessary to obtain the distance by calculation. Suppose that the transit line AC (Fig. 17) crosses a

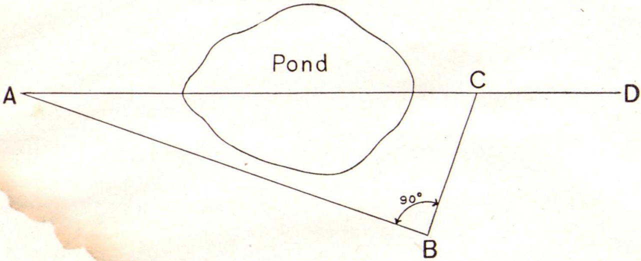


Fig. 17

pond and the distance AD is required. With the transit at A, measure the angle CAB, from C to any convenient point B. B should be so chosen that AB may be measured without difficulty. At B turn off 90° and set C at the intersection of the original transit line AC and the new line BC. Measure AB. Then calculate AC by the formula $AC = AB \div \cos A$. If we measure BC, we may check this by the equation $AC = BC \div \sin A$. The measured distance CD added to the calculated distance AC gives the required distance AD.

If it is not convenient or possible to use the right triangle, we may set B in any position, thus forming an oblique triangle ABC (or ABD). If we measure one side AB and two (or better, three) of the angles, we may solve this triangle for AC (or AD). (See page 39.)

To Find the Volume of Earth Removed from a Gravel Pit

Before any material is removed, lay out squares 10 ft. or 20 ft. on a side as shown in Fig. 18, driving

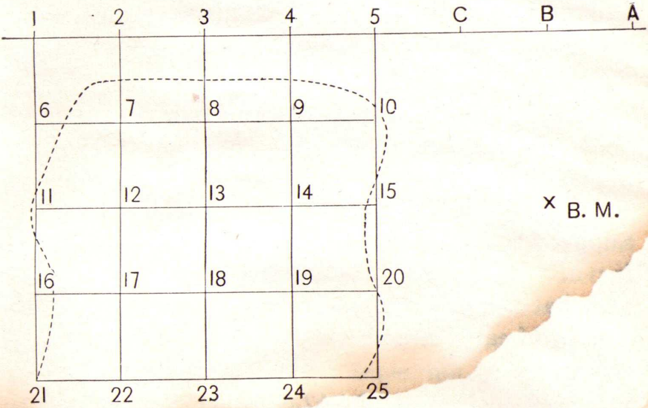


Fig. 18

a stake at each corner. Give these points reference numbers to be used in the notes. At all the points where the material may be removed, take levels on the ground at the stake, and record these levels in the notebook. As all of the stakes may be knocked out and the positions lost, it is advisable to preserve the lines by extending one or two of them into a region beyond the digging operations, as at ABC.

Also keep a Bench Mark, or a point of known elevation, which can be used as a reference when all the stakes are lost. For instance, a spike may be driven into a tree (at B.M.) and the difference in level between it and point 15 may be taken and recorded.

After the material has been taken from the pit, re-set the stakes (if necessary), and take a new set of levels and record them. Start from the Bench Mark, checking on any stakes which are found. From these notes, find the depth of cut at each stake, that is, the difference between the old level and the new level.

The number of cubic yards in any one of these square blocks (prisms) may be figured by taking the average of the four corner depths and multiplying this by the area of one square and dividing by 27. Suppose, for example, that at 7 we find a cut of 9.2 ft.; at 8, 10.0 ft.; at 13, 12.0 ft.; and at 12, 12.6 ft.; and that the side of the square is 10 feet. Then the volume of earth removed is

$$\text{Vol.} = \frac{9.2+10.0+12.0+12.6}{4} \times \frac{100}{27} = 40.6 \text{ cu. yds.}$$

The fractional parts of squares, like that between 7, 8 and 2, 3, will have to be estimated. If we measure from 8 toward 3 to the edge of the pit, and from 7 toward 2 to the edge of the pit, we will have the dimensions of a wedge-shaped piece which can be computed approximately. Suppose the distance out from 8 is 6 ft. and that the distance out from 7 is 5 ft. We then have a wedge-shaped piece whose dimensions are approximately 5.5 ft. $\times$ 10 ft. on top and whose depth is about 9.6 ft. Its volume equals the area of the top times one-half the depth, or 264 cu. ft. or 9.8 cu. yds.

Notes on Trigonometry

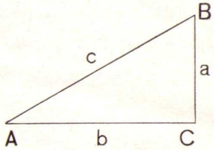


Fig. 19

In any right triangle, such as ABC (Fig. 19) the relations of the different sides are given different names and these "functions," as they are called, have definite relations to the angles of the triangle. In trigonometry, it is customary to indicate angles by large letters and sides by small letters. The ratio a/c is called the sine of A and is written sin A. Its value can be found for any angle in the table on page 43. The ratio b/c is the cosine of A and is written cos A. The ratio a/b is called tangent of A, written tan A. The ratio b/a is the cotangent of A, written cot A. The values of these functions depend upon the size of the angle, not upon the size of the triangle; the sine of 20° is always .34202 no matter where the angle occurs. It may be in an oblique triangle or it may not be in any triangle. The values of these functions for every whole degree from 0° to 90° will be found on page 43. Notice that these functions given at the top of the page follow down the page according to the degree of angle at the left, until the angle 45° is reached. Then they change; the degrees go up the page on the right, and the names of the functions are at the bottom of the page. That is, the sine of 30° is the same number as the cosine of 60°.

For angles greater than 90°, we must observe the following rule for signs. If A is greater than

90°, then sin A = sin (180°—A); that is, the sine of an angle and the sine of its supplement are the same. cos A = —cos (180°—A); that is, the cosine of an obtuse angle is the same as that of its supplement with a negative sign prefixed. Also tan A = —tan (180°—A), and cot A = —cot (180°—A).

If we know any three of the six parts (three sides and three angles) of a triangle, we can find the other three, provided one of the known parts is a side. One side at least must always be known or we cannot "solve" the triangle.

Right Triangles.

Referring to Fig. 19, we have the following relations:

$a=c \sin A$	$b=c \sin B$
$b=c \cos A$	$a=c \cos B$
$a=b \tan A$	$b=a \tan B$
$b=a \cot A$	$a=b \cot B$

$$c=\frac{a}{\sin A}=\frac{b}{\cos A}=\frac{b}{\sin B}=\frac{a}{\cos B}$$

With these equations any right triangle may be "solved" and the required parts found, provided two other parts are known, one of them being a side. To apply the formula literally, the triangle must be lettered like that in Fig. 19. Example:

Given c=100.0 ft., A=20°, c=90°; required a and b and B.

Then $a=100\times\sin 20°=100.\times.34202=34.202$ ft.
Also $b=100\times\cos 20°=100.\times.93969=93.969$ ft.

Since the sum of the angles of a plane triangle always equals 180°, the angle B must be 70°. Hence all the parts are known and the triangle is "solved."

Oblique Triangles.

Oblique triangles may nearly always be divided up into right triangles, so the preceding formulas are sufficient to deal with most cases. Other formulas are sometimes very useful, however. In any oblique triangle, as in Fig. 20, we have the relations,

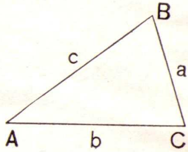


Fig. 20

$$\frac{a}{b} = \frac{\sin A}{\sin B} \qquad \frac{a}{c} = \frac{\sin A}{\sin C} \qquad \frac{b}{c} = \frac{\sin B}{\sin C}$$

That is, if we know an angle and its opposite side, and also another angle or a side, we may calculate the part opposite to the latter. Suppose that b=100 ft., B=60°, and A=40°; find a.

$$\text{Formula, } a = b \sin A / \sin B = \frac{100 \times .64279}{.86603} = 74.22 \text{ ft.}$$

Another useful formula is

$$a^2 = b^2 + c^2 - 2\ b\ c \cos A.$$

If we know two sides (b and c) and the angle between them (A), we may find the side (a) opposite this angle. Also it is possible to find A, when a, b and c are known. Whenever two angles are known, it is easy to find the third by subtracting their sum from 180°.

Example of Oblique Triangle Solved by Right Triangles.

Suppose c=50 ft., b=60 ft., A=45°. Find (a) (Fig. 21). Drop a perpendicular BD. By an

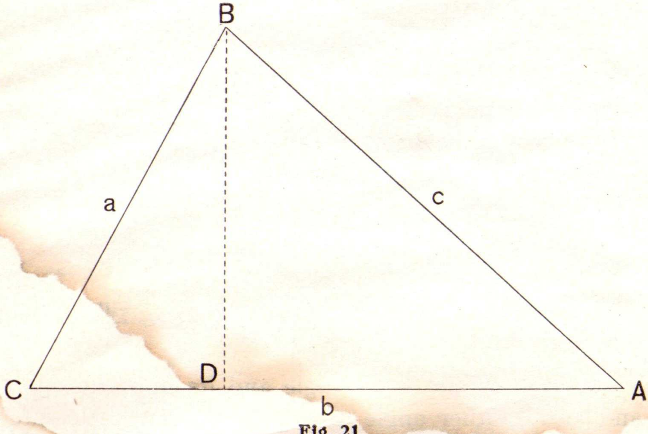


Fig. 21

application of the right-triangle formulas, we first find AD and BD in the right triangle containing A.

$BD = c \sin A$	and	$AD = c \cos A$
$= 50 \times .70711$		$= 50 \times .70711$
$= 35.36$ ft.		$= 35.36$ ft.

CD is, therefore, equal to AC—AD=24.64 ft. Now in triangle CBD we know two sides, and D is a right angle. Therefore, $35.36 \div 24.64 = \tan C = 1.435$. From the table (page 43) we find that Angle C= 55° 08′. To find the minutes of the angle proceed as follows:

$\tan 56° = 1.4826$	$\tan C = 1.435$
$\tan 55° = 1.4281$	$\tan 55° = 1.4281$
Diff. for 60′ = .0545	Difference = .0069

$$\frac{69}{545} \times 60' = 7'\ 6, \text{ or } 8' \text{ to the nearest whole minute;}$$

therefore, angle $C = 55^\circ\ 08'$

To find the side (a), we have

$$a = DB \div \sin C = 35.36 \div .82048 = 43.10 \text{ ft.}$$

Or, by the square root of the sum of the squares of the sides,

$$a = \sqrt{(35.36)^2 + (24.64)^2} = 43.10$$

Areas of Oblique Triangles.

If we know two sides and the angle between them, then

$$\text{Area} = \tfrac{1}{2}\ b\ c \sin A.$$

If we know two angles and one side we may use the formula

$$\text{Area} = \frac{a^2 \sin B \sin C}{2 \sin A}$$

If all three sides are known the area is found by

$$\text{Area} = \sqrt{(\ s\ (s-a)\ (s-b)\ (s-c)\ )}$$

in which $s = \dfrac{a+b+c}{2}$

Use of Tables

When an angle is a whole degree, its function is found at once in the table. If the angle is not a whole number of degrees, we must interpolate between

the numbers in the table. Suppose we are to find the sine of 70° 50′ and also the cosine of that angle. We first take the difference between the values for 70° and for 71° (which is the change for 60′) and then compute the proportional part of this corresponding to 50′, and add this result to the value for 70° in the case of the sine, subtract it in case of the cosine.

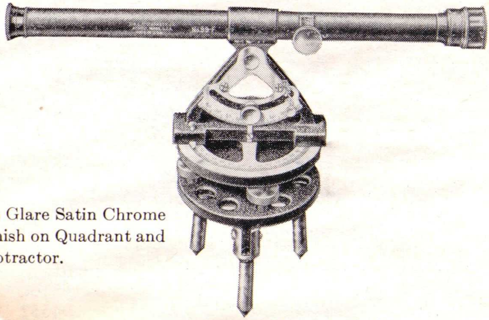
$\sin 71° = .94552$	$\cos 70° = .34202$
$\sin 70° = .93969$	$\cos 71° = .32557$
Diff. for $60' = .00583$	Diff. for $60' = .01645$
$\frac{50}{60} \times .00583 = .00486$	$\frac{50}{60} \times .01645 = .01371$
$\sin 70° \; 50' = .94455$	$\cos 70° \; 50' = .32831$

If we require the tangent of 28° ½ or 28° 30′, it will be half-way between that for 28° and for 29°. If the angle is 28° 15′ the tangent will be one-fourth the way from tan 28° to tan 29°. For the sine and tangent add the correction; for cosine and cotangent subtract the correction.

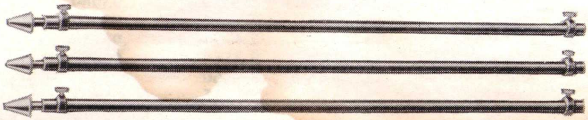
To find the minutes of an angle obtained from its sine, cosine, tangent or cotangent, take the difference between the function for the next lower whole degree and the given function, then take the difference between the function for the next lower and the next higher degree in the table, divide the former by the latter and then multiply by 60′. (See example on page 40.)

o	Sine	Tangent	Cotangent	Cosine	o
0	.00000	.00000	Infinite	1.0000	90
1	.01745	.01745	57.290	.99985	89
2	.03490	.03492	28.636	.99939	88
3	.05234	.05241	19.081	.99863	87
4	.06976	.06993	14.301	.99756	86
5	.08716	.08749	11.430	.99619	85
6	.10453	.10510	9.5144	.99452	84
7	.12187	.12278	8.1443	.99255	83
8	.13917	.14054	7.1154	.99027	82
9	.15643	.15838	6.3138	.98769	81
10	.17365	.17633	5.6713	.98481	80
11	.19081	.19438	5.1446	.98163	79
12	.20791	.21256	4.7046	.97815	78
13	.22495	.23087	4.3315	.97437	77
14	.24192	.24933	4.0108	.97030	76
15	.25882	.26795	3.7320	.96593	75
16	.27564	.28674	3.4874	.96126	74
17	.29237	.30573	3.2709	.95630	73
18	.30902	.32492	3.0777	.95106	72
19	.32557	.34433	2.9042	.94552	71
20	.34202	.36397	2.7475	.93969	70
21	.35837	.38386	2.6051	.93358	69
22	.37461	.40403	2.4751	.92718	68
23	.39073	.42447	2.3559	.92050	67
24	.40674	.44523	2.2460	.91355	66
25	.42262	.46631	2.1445	.90631	65
26	.43837	.48773	2.0503	.89879	64
27	.45399	.50952	1.9626	.89101	63
28	.46947	.53171	1.8807	.88295	62
29	.48481	.55431	1.8040	.87462	61
30	.50000	.57735	1.7320	.86603	60
31	.51504	.60086	1.6643	.85717	59
32	.52992	.62487	1.6003	.84805	58
33	.54464	.64941	1.5399	.83867	57
34	.55919	.67451	1.4826	.82904	56
35	.57358	.70021	1.4281	.81915	55
36	.58779	.72654	1.3764	.80902	54
37	.60181	.75355	1.3270	.79864	53
38	.61566	.78129	1.2799	.78801	52
39	.62932	.80978	1.2349	.77715	51
40	.64279	.83910	1.1918	.76604	50
41	.65606	.86929	1.1504	.75471	49
42	.66913	.90040	1.1106	.74314	48
43	.68200	.93251	1.0724	.73135	47
44	.69466	.96569	1.0355	.71934	46
45	.70711	1.0000	1.0000	.70711	45
o	**Cosine**	**Cotangent**	**Tangent**	**Sine**	**o**

Starrett Transit
No. 99



No Glare Satin Chrome
Finish on Quadrant and
Protractor.



The PLAIN SIGHT TUBE has no lenses, is brass, twelve inches long; in one end is a small eye aperture, in the other the usual cross wires.

The TELESCOPE has cross lines, is adjustable to distances, and is same size and length as plain sight tube. The lens is well protected from dirt and breakage by a friction cap, and a shutter for the eye aperture.

With short legs, as shown in the cut, the instrument is eight inches high. With long extension legs, which fasten on over the short legs, the height can be adjusted from two feet eight inches to four feet eight inches. The sight tube and level case are nickel plated, the other parts are enameled. No-glare Satin Chrome Finish on quadrant and protractor.

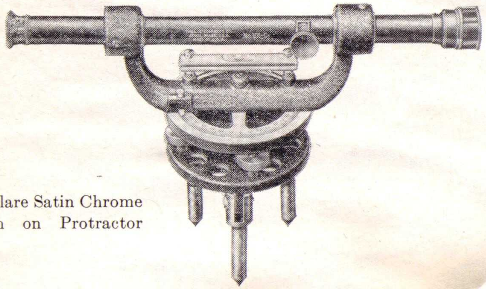
The advantages of this transit are as follows: The head is held to the tripod with a bolt and knurled nut, so as to make it stationary at any given point; the graduated arc can be clamped to the base-plate by throwing a small cam arrangement, and a spring indexing finger to mesh in the arc graduations. The transit with short legs is housed in an attractive, highly finished, sycamore carrying case about 4¾ inches x 9½ inches x 13¾ inches, with a leather strap running completely over the box cover. Weighs approximately 8 lbs., making it easily carried about. The extension legs are not packed in the box. They weigh about 6 lbs., so when used with the short legs the transit weighs about 11 lbs.

Directions for setting up and using are inclosed with each transit.
Furnished in sycamore carrying case.
Weight packed in box for shipment approximately 20 pounds.

PRICES

No. 99 B With plain sight tube, long legs and plain level vial....... [redacted] $53.0
No. 99 F With telescope, long legs, and ground level vial.......... 72.5

Starrett Leveling Instrument No. 101



No-Glare Satin Chrome Finish on Protractor

It should be borne in mind that our leveling instruments do all that a transit will do except measure vertical angles. These instruments attain angles in a horizontal plane only, and are designed for the use of farmers, contractors, carpenters, millwrights, masons, surveyors, etc.

Its lightness, simple construction, and moderate price, combined with the wide range of work to which it can be applied, make it very desirable for all who have occasion to use such an instrument. The upper plate is connected to the tripod head by a ball and socket joint, and is leveled by the leveling screws. This plate is recessed to contain a graduated arc for taking angles, and on the plate is the frame with level and sight tube for taking horizontal angles only. The nickel plated SIGHT TUBE on the No. 101A is PLAIN, with no lenses, 12 in. long, with small eye aperture and the usual cross wires. The TELESCOPE on the No. 101C is the same as that used on the No. 99F Transit. It has cross lines, is adjustable to distances, and is the same size and length as plain sight tube. Other features are precisely the same as the transit described and shown on the preceding page.

Directions for setting up and using are inclosed with each leveling instrument.

Furnished in sycamore carrying case.

Weight, packed in box for shipment, approximately 20 pounds.

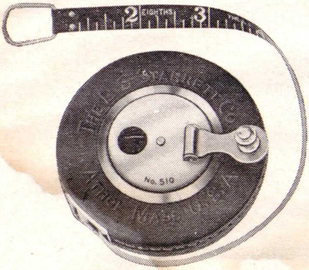
PRICES

No. 101A With plain sight tube, long legs and plain level vial. . . . . [redacted] **$45.00**

No. 101C With telescope, long legs and ground level vial. . . . . [redacted] **64.50**

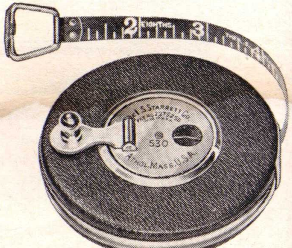
Starrett Steel Tapes

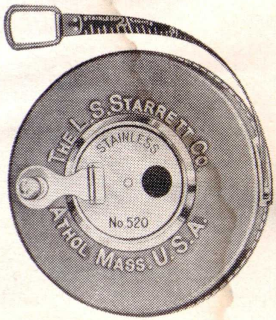
To lay off desired distances accurately along the lines determined by the transit and level, it is necessary to have some standard of measurement. Starrett Steel Tapes are made in a large variety of styles, in different lengths up to 100 feet and graduated in convenient, easy reading units. They may be depended upon absolutely for accuracy. Information on styles other than these illustrated may be obtained in our catalog.



No. 510 A superior steel measuring tape in a metal-lined leather case, with patent extension push button handle which is flush with case when closed. Quick reading feature eliminates errors and saves time. Available in English and/or Metric graduations. Also can be furnished with graduations in links and poles on special order. Well made, dependable and highly accurate.

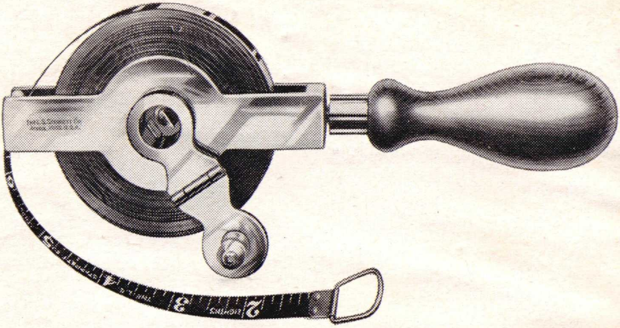
No. 530 An extremely moderate priced steel tape without sacrificing durability. Easy reading graduations are bright against dark background, black artificial leather covered case with push button and folding handle, all metal parts have bright nickel finish. The popular priced tape with Starrett dependability.



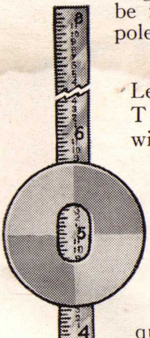


No. 520 This Stainless Steel Tape is indispensable for wet, muddy work, or any place where rust and corrosion play havoc. Easily cleaned, the quick reading markings stay sharp and bright. Comes in 50 and 100 foot lengths in leather case and push button handle. Ideal for construction work where real service and accuracy is necessary.

For complete information and prices write for Catalog No. 26A.



No. 537 Starrett Reel Measuring Tape is particularly useful for certain kinds of work. Rugged, nickeled frame with hardwood handle and folding winding handle. Has quick reading feature and available with English and/or Metric graduations. Also can be furnished with graduations in links and poles on special order.

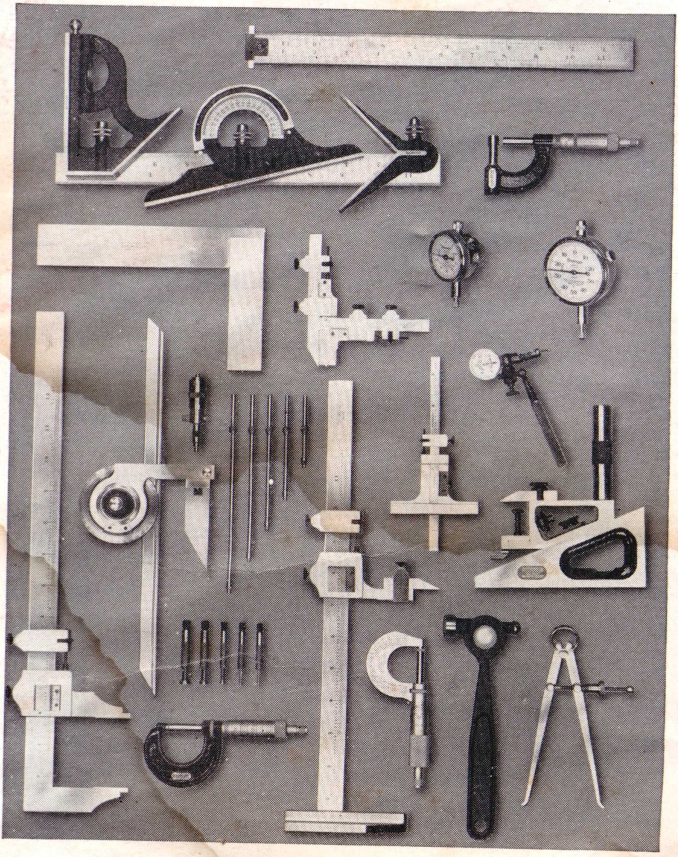


Starrett **No. 999** Leveling Rod and Target, for use with Transits and Leveling Instruments. Made of seasoned stock. The rod has two 4-foot sections, easily and quickly aligned by a positive lock, making a total of 8 feet. The bottom of the rod is steel capped.

No. 87 Starrett Mercury Plumb Bob has patented device for fastening the string without a knot to tie or untie which allows the bob to hang perfectly true. Made of Steel, bored and filled with mercury. Hardened and ground point. Low center of gravity. Nickel Plated.

Starrett Tools are recognized throughout the world as the standard for accuracy, workmanship, design and finish. Over 3000 are described in the Starrett General Catalog No. 26A. Sent on request.

Standard of Precision



Over 3,000 types and sizes of precision tools in the STARRETT *Complete Line . . . One Dependable Source to Meet All Your Requirements.* Write for your copy of the Free STARRETT CATALOG.

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